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Can Nuclear Power be Adopted to Sri Lanka as a Solution to the Energy Crisis?

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In the light of recent events, Sri Lanka has turned its focus on alternative electricity sources as the existing power sources such as hydro, fossil fuel and biomass systems have proved insufficient to accommodate the increasing electricity demand in the country. Hence, Sri Lanka may consider adopting nuclear power as an effective solution for the future power crisis.

Nuclear power generates electricity using nuclear fuel as the power generation source. Even though nuclear power generates electricity in a similar mechanism to thermal power, it does not involve any fuel burning.

Fission reactions

Fissionable uranium, that is ^{235}U isotope, which is the most popular nuclear fuel, can produce very high thermal energy when it undergoes fission reactions with neutrons in a nuclear reactor. In fission reactions, ^{235}U splits into two smaller elements and neutrons as given in the following few examples.

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}Ba + {}^{92}Kr + 3\,{}^{1}_{0}n $$

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{137}Cs + {}^{92}Rb + 3\,{}^{1}_{0}n $$

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{1461}La + {}^{87}Br + 3\,{}^{1}_{0}n $$

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{144}Xe + {}^{90}Sr + 2\,{}^{1}_{0}n $$

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{137}Te + {}^{97}Zr + 2\,{}^{1}_{0}n $$

As given in the above examples of fission reactions, neutrons continuously get regenerated from the fission reactions itself and therefore only the initial neutron supply is sufficient to maintain fission reactions in a nuclear fuel reactor. Each fission reaction heat is generated as a biproduct. With millions of such reactions can undergo in a nuclear reactor that would lead to generate massive heat energy.

The heat generated from these fission reactions is transferred to the reactor fluid inside the reactor. This absorbed heat by the reactor fluid is then converted to steam that drives to operate the steam turbines, like any other thermal power station.

Fusion reaction

Alternative to fission reactions nuclear energy can be produced using fusion reactions. However, fusion reactions are still under experimental state. In fusion reactions two or more smaller mass elements fused together produces larger element.

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n $$

Unlike fission reactions, fusion reactions produce no radioactive by products. However, fusion reaction to initiate need the particles to be energized to overcome the Coulombic barrier. This occurs only when the reactants are in plasma state at very high temperature as 15 000 000 K. Naturally fusion reactions occur in stars under such high temperature. Even though this sounds quite unrealistic to have such vigorous reaction under laboratory conditions, scientists are successfully experimenting on nuclear fusion. One good example was the recent breakthrough showcased from US National Ignition Facility in California demonstrating fusion reactions exceeding high powered lasers under laboratory conditions.

Advantages of nuclear power as energy source

According to US Energy Information Administration, nuclear power has 92% capacity factor which is the highest of all the other main power generation sources. It is more than twice of the capacity factors of coal power and hydropower having 40% and 41.5% capacity factors respectively. Nuclear fuel needs to refueling only in 1.5 to 2 years, unlike power generation using fossil fuel which needs continuous supply of fuel. Even though fossil fuels are predicted to be running out in next 30 years, nuclear fuel is available on earth for more than 70 years. Furthermore, nuclear power has the advantage of regenerating the used fuel so that it does not need to rely on fresh nuclear fuel.

Most important advantage of nuclear power is that it is a green energy source. Compared to fossil fuel burning, nuclear power has no contribution to green house gas effect and air pollution since the heat energy produce only via fission reactions. Replacing nuclear power from fossil fuel can indirectly save many deaths of humans, animals and plants.

Can we adopt nuclear power to Sri Lanka?

There are 19 aspects in which International Atomic Energy Authority (IAEA) listed on initiating nuclear power in a country. A pre-feasibility study has been carried out on launching a nuclear power plant in Sri Lanka considering few selected topics namely: National position, Environmental Protection, Site and supporting facilities, Nuclear fuel and radioactive waste management, Human resource development, Nuclear safety, Nuclear Security, Radiation protection.

Aspects related to above topics are discussed in the following sections.

National Position

Cabinet approval is required for adopting nuclear power to Sri Lanka under the Ministry of Power and Renewable Energy with the assistance of International Atomic Energy Authority (IAEA). Furthermore, Sri Lanka Atomic Energy Board (SLAEB) has carried out phase 1 of IAEA's Integrated Nuclear Infrastructure Review (INIR) in 2021 where they have engaged with the relevant stakeholders in a potential nuclear power plant project (Atomic Energy Board of Sri Lanka, 2022).

In 2019 United States Energy Information Administration (USEIA) carried out a study on the capital cost and performance of new utility-scale electric power generating technologies (U.S. Energy Information Administration, 2020). The performance specifications and cost estimations of nuclear power technology compared to other power generating technologies according to this study, are summarized in Table 1.

Table 1: Performance specifications and cost estimation of coal and nuclear power generation technologies (Source: United State Energy Information Administration) (Btu: British thermal units)

Technology	Net Capacity (MW)	Heat Rate (Btu/kWh)	Capital Cost ($/kW)	Fixed Cost ($/kW-years)	Variable Cost ($/MWh)	Sulfur dioxide (SO_2) emission (lb/MMBtu)	Nitrogen oxides (NO_x) emission (lb/MMBtu)	Carbon dioxide (CO_2) emission (lb/MMBtu)
Coal	650	8638	3636	42.10	4.60	0.1	0.06	206
Coal with Carbon capturing	650	9751	5084	70.0	7.10	0.02	0.06	144
Advanced Nuclear Reactor	2156	10608	6041	121.64	2.37	0	0	0
Small Nuclear Reactor	600	10046	6191	95.00	3.00	0	0	0
Solar	115	N/A	7221	85.4	0	0	0	0

Table 2 compares the summarized economic profiles of coal power and nuclear power technologies. These data were analyzed by a postgraduate student for the thesis submitted for a MSc degree at the Department of Nuclear Science, University of Colombo (Jayakody, 2018).

Table 2: Summarized economic profile of Power generation technologies

*Profit is calculated assuming an annual unit selling price of Rs15/kWh

Technology	Annual unit generation cost per kWh	Life span (years)	Net profit during life span*
Nuclear Power	Rs. 2.72	60	Rs. Billion 12312.01
Coal with CCS	Rs 11.29	30	Rs billion 111.62
Coal without CCS	Rs 11.92	30	Rs billion 151.18

According to the data given in Table 1 and 2, the high capital cost will be the main obstacle for Sri Lanka to initiate a nuclear power plant. Yet in the long run, nuclear power plant operation will yield a remarkable net profit, with regard to low operational cost, zero carbon emission, low annual unit generation cost and life span, compared to coal power technologies.

Environmental Protection

The construction of the nuclear power plant will alter the land use at the proximity of the plant site and its surroundings. Agricultural and residential areas near to the power plant must be removed for safety purposes. If the power plant is planned to be constructed close to a coastal area, then a significant region along the coast has to be named as a restricted area for fishing, marine activities and tourism. In addition, the high-tension power line that is directed away from the plant will restrict land use on a strip 80–100 meters wide depending on the column type. Trees cannot be grown or maintained and buildings or other structures taller than 2 meters cannot be built in the immediate vicinity of the power line.

Decommissioning of a nuclear power plant is an administrative and technical process. It comprises removal of radioactivity residuals and progressive demolition of the plant. Once a nuclear power plant facility is fully decommissioned any sort of danger related to radioactivity should not persist. The costs of decommissioning are to be spread over the lifetime of a facility and saved in a decommissioning fund. After a facility has been completely decommissioned the power plant premises must be able to be used as a usual land.

Most of the commercial nuclear power plants use a water based recirculating cooling system to condense the steam. In general, nuclear power plants operate at lower temperatures and lower turbine efficiency. Hence, nuclear plants extract and consume more water per unit of electricity produced than coal plants that use similar cooling technologies. Apart from energy transfer and steam condensation, nuclear power plants use water to keep the reactor core and fuel rods cool. Water produced from the condensed steam is reused in the generation process. However, the water used for cooling is discharged back into the lake, river or ocean. According to the Sri Lankan government standards the temperature of the water discharge into marine coastal areas must be below 45 0C at the point of discharge. If the nuclear power option is adopted by the country a proper mechanism must be implemented to meet this water discharging standard.

During its operational status nuclear power plants have not had any significant impact on flora and fauna. The damage occurs only in an event of a major accident and the destruction it brings on the plants and animals in such an event is severe and unrecoverable. Disaster areas such as Fukushima in Japan and the Chernobyl in the USSR show some of these effects on animals and plants.

Site and Supporting Facilities

When seeking a site for a nuclear power plant, authorities inevitably face the challenge of balancing the engineering and economic factors. The reason is, a nuclear power plant facility requires a larger land site compared to the other conventional thermal power plants in order to minimize the radioactive risk. According to the international security and safety standards of a nuclear plant, a safety buffer zone that is defined based on the capacity of the reactor must be established around the power plant in order minimize potential radiation hazards for the close residential areas in the event of major accident. This claims more compensation and hence increases the initial cost of the power plant installation. The other factors to consider for a nuclear power plant site are water sources, distance to the national power grid, road network, population distribution, seismicity, geology, meteorology, other environmental features such as Tsunami, flood, cyclone. Nuclear power plant should be located with easy access to water sources and main road network, close proximity to substations of electric grids and with less population density (Jayakody, 2018).

Fuel cycle and radioactive waste management

According to international nuclear waste disposal concepts, a country can adopt the following two disposal methods suitably. They are; near-surface disposal method for short-lived low level radioactive waste and deep geological disposal method for long-lived high-level radioactive waste. Since Sri Lanka is small in land mass it is very difficult to find a proper site for nuclear waste disposal. In addition, the potential to harm from nuclear waste to ground water sources has to be minimized when selecting a nuclear waste dumping site. The concept of a mountain nuclear waste repository is being put into practice by some countries. Eg USA is examining the possibilities of using the Yucca Mountain site in Nevada as its first national Mountain nuclear waste repository site. Nevertheless, a substantial capital has to be spent on developing such disposal grounds and auxiliary facilities (Hanks et al., n.d.) . In Europe, a concept has been put forward to place the nuclear waste in high integrity steel containers and then store in excavated tunnels 230 metres deep within a ductile clay (Storage and Disposal Options for Radioactive Waste, 2021).

IAEA suggests that there should be policies and strategies of nuclear waste management produced due to used fuel and other nuclear waste considering the national situation in terms of legal framework, technical and organizational structure (International Atomic Energy Agency, 2016).

Choice of the nuclear reactors

Pressurized Water Reactor (PWR) models being the most popular nuclear reactors all around the world are available with different types, namely VVER (Water-water energetic reactor), APR-1000, CPR -1000 and AP 1000. An Extensive feasibility study should be carried out on choosing the most feasible reactor in the Sri Lankan context. Based on the reactor safety goals, previous operational experiences and the reliability VVER1000 model and AP-1000 model can be recommended as suitable reactor models for Sri Lanka. In making this recommendation the priority should be given to the technological features of the reactors. The power output of VVER models ranges from 70 to 1700 MW. AP-1000 is also an 1100 MW class PWR technology-based reactor which has been developed utilizing the technology of AP600 design.

Small Modular Reactors (SMR) is another technology which can be incorporated to Sri Lankan national grid as an alternative power source. SMRs are nuclear power plants that are smaller in size (700 MW or even less than 300 MW) than most current generation base load plants (1,000 MW or higher). These smaller designs can be transported by truck or rail to a nuclear power site. SMRs are being developed to provide a flexible, cost-effective energy for various applications.

Human Resources Development

At present, two official government bodies have been established to promote and regulate Nuclear Technology related works in Sri Lanka. They are the Sri Lanka Atomic Energy Board (SLAEB) and Sri Lanka Atomic Energy Regulatory council (SLAERC). SLAEB has the responsibility of facilitating the utilization of nuclear technology for national development in the country and providing radiation protection services for regulating the practices of ionizing radiations. SLAERC has the responsibility for regulating practices involving ionizing radiation, the safety and Non- Proliferation of nuclear weapons and the safeguards. In its current operation, SLAEB and SLAERC are in the process of developing human resources related to fields such as

1. Nuclear safety and security by enhancing detection capabilities and developing knowledgeable and skillful personnel; public awareness of radiation

protection by conducting workshops and awareness programs.

2. Environmental Protection by collecting and analyzing the data on baseline environmental radioactivity. In parallel human resource and measuring techniques related to environmental protection can be developed.
3. Emergency planning by developing measuring techniques and training emergency response teams and personnel for field measurements. The Nuclear Disaster Early Warning System has been maintained since 2012.
4. Formulation of national policies and strategies on protection against ionizing radiation, on the safety and security of sources and nuclear and other radioactive material and on radioactive waste management. (Source: Ministry of Power and renewable energy, Reports of performance 2017 and programs for 2018)

Furthermore, special attention must be paid on developing the human resources that are directly linked with the nuclear power plants. Training and degree programs must be launched in universities to train such personnel.

Awareness and acceptance of the general public on nuclear energy is vital for launching a nuclear power project in a country. The favorability for nuclear power among the majority of the people in Sri Lanka is still at a very low level. Long before launching nuclear power projects, the Government and the authorized institutes must initiate a strong public campaign to increase the awareness about nuclear power and its benefits.

Nuclear safety, nuclear security and radiation protection

Nuclear safety is the achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards. Nuclear security is the prevention and detection in response to theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities. Radiation protection refers to the protection of people from harmful effects of exposure to ionizing radiation, and the means for achieving radiation protection. In any nuclear based industries including nuclear power plants, nuclear safety, nuclear security and radiation protection are essential components and these 3 aspects are mostly interconnected.

The key aspects of the safety approaches, that should be adopted are: prevention; monitoring; action that include physical barriers between the radioactive reactor core and the environment; setting up of multiple safety systems each with backup systems to minimize human error; high-quality design, construction and equipment that prevent operational disturbances or human failures; constant monitoring and regular testing to detect equipment or operator failures and utilization of diverse systems to control damage to the fuel and prevent significant radioactive releases (International Atomic Energy Authority, 1996; International Atomic Energy Authority, 1999; Jayakumar, 2016)

When implementing a nuclear power generation facility in Sri Lanka special attention must be paid to the available safety features of the nuclear technology when selecting the suitable reactor type. Nuclear technology that incorporates more passive safety features can ensure higher responsiveness for emergency situations with a less external intervention. Special attention must be given when choosing materials for the components of reactor vessel and containment building. The feasibility for decontamination of the components also must be taken into consideration.

In terms of nuclear security, it is necessary to maintain a strong national level legislative and regulatory framework in compliance with the international legal instruments. An efficient security system must have the capacity of handling issues relating to theft, sabotage, unauthorized access and illegal transfer or other malicious acts involving nuclear fuel and other radioactive by-products of a power plant.

Radiation Safety Measures

Nuclear power plants use fissile materials to produce energy and as a by-product of this process, ionizing radiation is released in abundance. Safety barriers should be available in the nuclear power plant to protect radiation workers from being exposed to hazardous radiations that cause microscopic damages to living tissues. In an event of nuclear accident and radiation leakage, workers are vulnerable to get exposed to heavy doses of such radiations. At high exposures, skin burns and radiation sickness, known as deterministic effects can occur. The fundamental countermeasures that reduce the exposure from external radiation doses are; increasing the distance from the radiation source, limiting the time of exposure and using radiation shielding.

In general, a monitoring system is used in nuclear power plants to determine the radiation exposure of individual staff members. This system includes internal and external monitoring methods. External monitoring methods are used to prevent hazardous situations like inhalation of radioactive materials in air and contamination of foodstuff and drinking water which may occur due to radiation leakage inside the nuclear power plant. Internal monitoring methods such as whole-body count and urine count are used to determine the level of radioactive materials deposited inside the body.

Recommendations of improving radiation safety measures

In anticipation of adopting nuclear power generation in the country, several issues have to be addressed in relation to radiation protection. Some of the suggestions which can resolve such issues are given below:

1. Atomic Energy Act 40 of 2014 has no provision to develop regulations for nuclear power plants or fuel cycle. Amendment to the act and nuclear power regulations should be established once the Government takes a decision to adopt nuclear power generation.
2. Sri Lanka lacks expert personnel in the field of radiation protection measures of a nuclear power plant. Hence, human resources must be developed by providing foreign training opportunities.
3. Degree programs in radiation protection and nuclear engineering up to post-graduate level must be initiated in local Universities.
4. Laboratory and research facilities related to radiation protection must be enhanced.
5. Job-oriented training and workshops for radiation workers, response teams, rescue teams and border security must be organized in collaboration with foreign institutes.
6. Appropriate ways and means to improve public awareness must be developed.
7. Number of monitoring stations should be increased when adopting the nuclear power option to the country

Many countries across the globe have started shifting to alternative power sources due to the scarcity of conventional fossil fuel. As for Sri Lanka, the cost for fossil fuel has already become unbearable and we could only assume that the problem would worsen if the prices escalated. The available renewable energy sources such as wind, solar and biomass also have limitations and are economically non-viable as standalone energy sources. Nuclear Power has the potential to be a feasible and sustainable solution in overcoming the energy crisis of Sri Lanka. Therefore, it is advisable that professionals and authorities spend more time and effort on implementing a nuclear power plant in Sri Lanka.

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Heading towards a renewable energy rich power system

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The Cabinet of Sri Lanka (Decision dated July 27, 2021) approved the commitment of achieving 70% renewable energy in electricity generation by 2030 made under Nationally Determined Contributions (NDC) to the United Nations Convention on Climate Change. Achieving this target leads to operating our power system entirely by renewable energy sources, including 1608 MW of large hydro power plants (saturated from 2025 onwards) and about 400 MW of small hydro power plants, in some periods of the year. This article discusses the practical and pragmatic approach towards integrating a high proportion of renewable energy into our national network.

What are renewable energy sources?

Renewable energy sources are inexhaustible energy sources that do not produce Green House Gasses. Established technologies include wind power, hydro, solar photovoltaic, landfill gas, energy from municipal waste, biomass and geothermal generation. Emerging technologies include tidal stream, wave-power and solar thermal generation. Out of these technologies, wind, solar, energy from municipal waste, biomass and geothermal generation are viable options for Sri Lanka. As municipal waste, biomass and geothermal uses conventional steam power plants, other two technologies are discussed in detail here.

Wind Power

Generating electricity from the wind is one of the most effective and rapidly growing ways of harnessing renewable energy and increasing numbers of wind turbines are being installed in many countries. Modern wind turbines can be very large with rotor diameters